RADIOACTIVE WASTE DISPOSAL – HOW SAFE SHOULD IT BE?
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ABSTRACT

The safety standard for the disposal of radioactive waste has evolved from the long-term storage or shallow burial practices of the 1950s to a graded approach depending on the characteristics and activity of the radioactive waste. In the 1950s, a decision was made in the United States to pursue disposal in deep, stable geologic formations for the higher activity, in particular transuranic and high-level radioactive waste. As a part of this decision, standards were developed that defined the design period of time for the isolation of the radioactive wastes disposed in these repositories from the public after closure. This paper discusses the evolution of the performance standards for geologic repositories, the development of the associated performance (containment) requirements, and the basic flaws in those approaches.

INTRODUCTION

In 1957, the Board on Radioactive Waste Management of the National Academy of Sciences (NAS) issued the report "The Disposal of Radioactive Waste on Land" [1] which stated: "*Unlike the disposal of any other type of waste, the hazard related to radioactive waste is so great that no element of doubt should be allowed to exist regarding safety.*" The report went on to state that *"Safe disposal means that the waste shall not come in contact with any living thing."* The board then qualified that to mean at least a 600 year isolation of radioactive wastes. They stated it could be substantially less if two of the longer life isotopes (strontium and cesium) were removed first.

The mandate for that Board originated with the Atomic Energy Commission (AEC), which had the responsibility for all radioactive waste management and disposal at that time. As early as the late 1940's, AEC reports [2-4] recognized that a longer-term solution was needed than just storing liquid radioactive wastes in tanks or drums and disposing solid radioactive waste in shallow burial sites. The problem increased in visibility and significance with the proliferation of nuclear weapons during the Cold War along with emergence of a nuclear power industry. The government's attitude was still the same as it was in World War II (WWII); namely, build the facilities to build he weapons and the worry about waste treatment and disposal later. This attitude was consistent throughout the country where strong emphasis was placed on technological development and economic growth with little consideration given to its impacts on human health and the environment. Many historians credit the emergence of an environmental consciousness to publication of Silent Spring by Rachel Carson in 1960.

In reviewing the 1957 NAS report and the other reports of conferences that proceeded (such as the 1955 Princeton Conference) [5] there is neither an explanation nor a justification, scientific or otherwise, for deciding the degree of safety required for radioactive waste disposal. The charge that the AEC gave to the attendees at the Princeton Conference was *"The problem (of radioactive waste disposal) really has two major categories: 1) where and how can we put wastes into the ground economically and under conditions that will not jeopardize the rights of others, especially in populated areas, and 2) what can we do with the large volume of wastes that have been and are yet to be produced…."* That charge had a vague reference to overall health and safety of radioactive waste disposal, but emphasized future waste management issues more than the present. In addition, there was an unstated condition that the proposed solutions should not require long-term active management.

Selection of waste disposal strategies in deep geologic repositories appears to result from some studies that concluded that shallow land burial had too much potential for impacts on public and environment if there were releases and would require long-term active management. Ocean disposal would eliminate the active management requirement (with the exception of monitoring), but was believed to be too risky in general and with respect to relatively near-term time frames. A review of those reports indicates that the health and safety issues associated with treatment, packaging, and transport of radioactive wastes were not considered. Protection of future generations was more important than protection of present day workers and public. While that view is probably not completely accurate, it is supported by the increase in the required safe disposal period for high-level waste disposal from 600 years in 1957 to 10,000 years in the 1990's (EPA regulations) to one million years recently required for Yucca Mountain [6].

EVOLUTION

A review of the evolution of the safe disposal period for the disposal of spent fuel, high-level waste (HLW) and transuranic waste (Greater than Class C in the Nuclear Regulatory Commission definitions) is an interesting study in political dynamics that indicate that perceptions and fear of the unknown were more important than scientific or technical facts. Particularly revealing are the supporting documents for the promulgation of the EPA radiation protection standard, 40CFR191, [7] the draft regulations which proposed a 10,000-year time frame for the risk or performance assessments. These calculations were required to show that deep geologic repositories would constitute no increased health risks due to radiation releases after closure. Indications are that there was an original increase in the regulatory period from 600 years to 1,000 years based upon concerns about the quantities of longer half-life radionuclides that would be present in the waste types proposed for deep geologic disposal. The increase of the time framed to 10,000 years proposed by EPA was mainly based upon generic performance assessments that showed that modeling potential changes for 1,000 years in the future did not allow enough time for reasonable discrimination among sites, while 100,000 years duration after closure was considered to be too uncertain because of climate cycles. An interesting progression in the logic for the extension of the compliance time periods given that the uncertainties of predicting the principal release mechanism – groundwater transport – are considered equal to or greater than those associated with predicting climate changes.

It is also notable that in contrast to all other EPA regulations, the regulations considered for radioactive waste disposal were the only EPA regulations specifically based on probabilistic risk assessments. This distinction is particularly significant when compared to regulations established under the Resource Conservation and Recovery of 1976, which established very proscriptive criteria for the treatment and disposal of hazardous wastes with virtually no reference to performance assessments or risk reductions. This dramatic difference in regulatory approach led to the new waste classification referred to as "Mixed Wastes" which are those which contain both hazardous constituents and are regulated by EPA, and those which contain radioactive materials and are regulated by the NRC.

Subsequent to the publication of the initial radiation standards in 1985, the EPA was taken to court primarily over the disparity in the standard between the protection period for an individual (1,000 years) and the general public (10,000 years) and because they had not considered the interrelationship of these rules with the Safe Drinking Water Act. Essentially, that court decision resulted in the EPA establishing equal compliance time requirements for both individuals and the general public for deep geologic repositories as 10,000 years as stated in the Final Rule which was promulgated in 1993. The justification by EPA for the 10,000 year time frame, as stated in their Final Rule Making documentation [8], was "*In the course of performing numerous risk assessments of radioactive waste disposal systems, the Agency has concluded that the risks identified over relatively short time spans, such as a few hundred to one thousand years, do not adequately portray important differences between important differences between alternative sites or disposal systems. This is because the ground water travel times would probably be sufficiently long at most sites that no significant radionuclide releases would be predicted over this time frame* (1,000 years). *If the analyses were carried further into the future, there could be substantial differences between the sites because of the hydrological or geochemical characteristics of their ground water systems. The primary risk assessments carried out in support of this rulemaking have thus been based on a time frame of 10 thousand years."* Of interest in the development of this rule was the concern over protection of future generations, which was achieved by increasing the health and safety risk of the current workers and general public.

What is interesting about this justification is that it was not based on the toxicity or other chemical or physical characteristics of the radioactive wastes being considered for deep geologic disposal or a life-cycle risk analysis or the known uncertainties of the inputs to the mathematical models used to forecast potential releases; rather it was selected as a 'standard' reference period for the comparison of disposal sites. The justification ignored that ultimately radioactive waste would be less hazardous than many hazardous wastes due to their decay, but the compliance periods for those wastes was established to only be hundreds of years. The attempt at long-term modeling that had been developed as a proposed qualitative tool to assist in determining which site might be better led to the promulgation of a performance standard that is being applied quantitatively. While the

10,000 year time period was applied to the certification of WIPP by EPA, it was successfully challenged with respect to Yucca Mountain, where a 1 million year time period was mandated by the courts. That challenge resulted from Congress which requested that the NAS provide site specific guidance for Yucca Mountain. Subsequently the panel selected by NAS stated that the stability of Yucca Mountain was on the order of 1 million years. Thus, the 1 million year planning horizon is only applicable to Yucca Mountain at present; however, it establishes a strong precedent for application to any future proposed deep geologic repositories.

JUSTIFICATION

From a scientific and technical perspective there is little justification for the selection of the 10,000-year time period for a number of reasons, including the accuracy of modeling any deep geologic system over that duration, the disparity between compliance time periods for radionuclides versus other toxic materials, particularly heavy metals, and the distinct possibility of climatological, natural, or social disruptions that will pose greater human and environmental risk than that from any natural release from a deep geological repository.

With respect to attempting to model the effects of disposing of radioactive waste for 10,000 years (or longer), the Board on Radioactive Waste Management of the National Academy of Sciences stated in a 1990 report: *"a scientifically sound objective of geophysical modeling is learning, over time, how to achieve the long-term isolation of radioactive waste. That is a profoundly different objective from predicting the detailed structure and behavior of a site before, or even after, it is probed in detail. Yet, in the face of public concerns about safety, it is the latter use to which models have been put. The Board believes that this is scientifically unsound."* The Board also stated *"to predict accurately the response of a complex mass of rock and groundwater as it reacts over thousands of years to the insertion of highly radioactive materials is not possible."* [8] This reflects the understanding by the general public that you can't predict the future with any certainty – simple weather forecasts being a prime example. The same public, however, derives some comfort by the explanation that 'eminent' scientists are able to model and predict that radioactive waste buried in WIPP, for example, will not cause harm; an interesting contradiction in itself.

It has been argued that there is a technical justification for the 10,000 years performance standard based on the half-lives of the radionuclides to be entombed. In contrast to the EPA, the Nuclear Regulatory Commission in the justification of their containment requirements, which range from 300 to 500 years for low-level waste, that *"uncertainties introduced by the heat generation rate and the fission product contributions to hazard can be compensated for by containment times in the range of several hundred to 1,000 years."* [10]. If the technical justification was based upon the risks of the specific radionuclides, then the basis should logically have been the more soluble radionuclides such as Sr-90, Cs-137, Tc-99 or I-129. For the first two, a 300 year time period would be sufficient to reduce their curie level by 90% and a 1,000 year time period would reduce their input to the overall hazard index for radioactive waste by over 95%. For Tc-99 and

I-129, however, their long half-lives mean essentially no change in concentration in 10,000 years so control of their toxicity has to be achieved by establishing low concentration limits for those radionuclides in the waste at the time of disposal.

In contrast, a panel appointed by the NAS to review the EPA regulations for Yucca Mountain recommended a regulatory approach with two distinct differences [11]. First, instead of calculating the risk to the public based on releases from the repository, they recommended establishment of a standard that limits the dose an individual can receive from the repository. Second, instead of a 10,000 or 10^6 planning horizon, the NAS recommended that the risk be calculated at the time when maximum risk occurs. These were estimated to be from tens to hundreds of thousands of years in the future, not a million years.

DISPARITY

A more significant scientific and technical issue with the establishment of performance time periods for the isolation of radioactive waste from the 'any living thing' is the disparity between the requirements for radioactive waste and other toxic waste. The toxic metals, such as arsenic, mercury, lead, etc. have no half-life – what is put in a landfill today will be there thousands or millions of years from now – though possibly in a different chemical form. Other organic and inorganic toxic wastes, such as PCBs, DDT, dioxin, etc, are known to resist decomposition for long periods under the conditions present in landfills. However, the design standard for hazardous waste landfills is to show containment for only 300 years after closure. An interesting example of the disparity is U-238. It is more hazardous as a heavy metal so logically the 300 year time period for containment should be applied to it as is for lead and other heavy metals. However, the disposal regulations for U-238 are based on its radioactivity not its heavy metal toxicity.

Another disparity is with the disposal of different types of radioactive waste. For many of the closed defense related nuclear sites including former uranium mills, Rocky Flats, Fernald, and others, a substantial amount of low-level radioactivity was left in place in shallow landfills. However, DOE has also established a Long-Term Stewardship program to maintain the integrity of those landfills and minimize the potential for releases. For low-level radioactive waste it was determined that long-term active management was acceptable, yet this same option has been dismissed out of hand for TRU and high-level radioactive waste. The hiatus of Yucca Mountain has effectively resulted in an active management approach for high-level waste as discussed later in this paper.

The emphasis of the EPA regulations for radioactive waste disposal are primarily based on health effects; protection of future generations who don't know any better (the regulations are based upon the loss in the future of "all present knowledge"). This direction is compounded by the propensity of the DOE to use overly conservative assumptions. Unfortunately, this propensity is encouraged by the history of the decisions made by regulatory agencies as discussed later – they tend to be very conservative based on the real fear of being sued and losing. At the same time, because of their mission directives from Congress, the EPA is forced to consider the potential releases from a deep geological repository and regulate them accordingly. As with other regulations, such as the NRC decision to require the use of the Probably Maximum Flood for the design of the low-level waste landfills, such regulatory isolation means that more time and energy is spent on very low probability, highly unpredictable future scenarios such as a possible radioactive release from a deep geologic repository at the expense of better solutions to minimizing the effects on man of such natural events as hurricanes etc. Such efforts result in an increase in the current health and safety risks to protect the future from a very improbable and unpredictable event. This becomes a very complicated argument. It devolves to a comparison of the risk of natural events (hurricanes, earthquakes, etc.) to risks from anthropogenic activities (radwaste disposal). In comparing the two, the arguments become moral and philosophical rather than based on quantitative economic calculations associated with the protection of human health and the environment.

In developing any environmental, health, or safety standard, the objective should be to balance the risk to the present population with the risk to future populations. With respect to the long term containment time period standards for disposal of transuranic and high-level waste, that balance does not appear to be included in the evaluation. The basic premise of occupational or worker health and safety is that any added steps to a process add the possibility for an accident or injury, so a holistic hazard analysis and risk assessment should be performed to ensure that the environmental or public health and safety gains are not at the expense of the workers. The integrated safety management approach should be applied to process design and to the regulations or certifications that affect process design. However, in determining the 10,000 year performance standard, there does not appear to be any consideration to the increased risk to the workers or public related to achieving that standard. Several examples demonstrate this premise.

First, during the conduct of the performance assessment required by EPA for the certification of WIPP (as described in 40CFR194), it was decided (apparently between DOE and EPA) that the performance assessment model would be very conservative to the point that some known and demonstrated scientific facts were ignored. For instance, there was a concern that there might be biological activity in WIPP following closure. This would release CO_2, which in turn would lower the pH and result in a greater dissolution of radionuclides into the brine and consequent transport out of WIPP if it was accidentally breached by future drilling activity. However, in evaluating this concern, DOE did not (or was not allowed) to take credit for the fact that the substantial amounts of zero valent iron in WIPP associated with the waste drums would raise the pH through electrolytic reactions. Ignoring this phenomenon resulted in the requirement to include large quantities of magnesium oxide (MgO) in WIPP as a buffer against the pH change. It is unfortunate that the EPA did not use their overall mandate for holistic environmental protection when making this decision. Their common risk assessment approach is to consider life-cycle affects (someone exposed to a pollution source for a human life time of ~70 years). However, consideration of the potential health and safety risks and environmental impacts associated with mining, transporting, and emplacing the MgO were essentially ignored in favor of the appearance of protecting the future generations.

It is also recognized that EPA has no mandate for worker protection, but they certainly have the freedom to request input from those parts of the federal government (OSHA, etc.) that do.

A second classic example is the requirement for closure to the underground disposal panels at WIPP after being filled with waste. As a result of the 10,000 year performance assessment, DOE proposed closing each panel with a concrete block wall and then, if necessary to pour a monolithic concrete plug at the opening to each panel. DOE had proposed four options for the closure system depending on the contents of the waste containers disposed in the panel. However, in the certification, EPA opted to be 'conservative' and selected the most rigorous of the four options and made it even more conservative by specifying the use of special cement. No consideration was apparently given to the potential health and safety risks to the workers while constructing those closures. Unfortunately, as soon as DOE implemented the installation of the concrete block wall, a worker was injured because of the weight and unwieldiness of the block design thus requiring a change in the design. Then, when they analyzed the construction requirements for installing the concrete monolith, they determined that they were impossible to safely construct and were able to get a deferment on their installation from the regulators. The point being, that in their concern for protecting future generations, both DOE and EPA were willing to put workers at risk and approve unnecessary environmental damage.

Both of these are examples of the single mindedness of regulations associated with protection of human health and safety. The regulations address one single risk factor but ignore all others. The examples presented show that it is acceptable to have activities that increase the current risk of injury or death due to construction for the sake of marginal reduction of future risk due to radiation induced cancer. Unfortunately, there are many examples of such regulatory contradictions on the books.

In addition to those the lack or incomplete consideration of those potential risks in the development of performance standards, the regulators have also continuously been overly conservative in the application of other requirements for radioactive waste disposal in deep geologic repositories such as WIPP and have mandated requirements that are both unnecessary and actually create additional health and safety risks for the workers. For example, the original NRC and EPA regulations for liquids in waste containers were developed based on the risks associated with the transportation and disposal methods at the time for hazardous and low-level radioactive wastes – namely regular semi trucks and shallow landfills. However for WIPP, which is more than 2000 feet below ground and has no potable groundwater sources below it and where the waste is transported in extremely sturdy transportation containers designed not to spill the contents under extreme conditions, the regulators (NRC, EPA, and state) all opted to continue the requirement for the removal of liquids from the waste containers. As a result, DOE is forced to open, treat and repack thousands of waste containers to remove liquids. This remediation involves opening the containers and often removing internal items – all work being done within gloveboxes. This adds a significant risk of accident/injury to the workers doing the remediation without lowering the actual risk to the public or WIPP disposal workers. A similar example is the requirement to remove pressurized containers, which is a subject of a separate paper in this symposium.

Finally, at present most of the non-defense high level waste (Spent Nuclear Fuel) is stored in Interim Storage Facilities (ISFs), generally at ground level, at nuclear reactors around the country. The design standards for those ISFs are for a 40 year life – the presumption is that by then a permanent disposal facility will be available. However, the public seems to be willing to accept the risks associated with the existing high-level waste storage – ISFs, tanks, etc. for the past 30 years rather than to accept a deep geological repository (Yucca Mountain) that would keep them isolated for thousands (if not millions) of years in the future. In other words, the public is willing to live with the idea that those wastes are being protected and will be in their lifetimes and probably the lifetimes or their children and grandchildren rather than insisting that safer disposal be expedited. Or at least the public as represented by the members of Congress – it is important to remember in discussions such as this that “the public” is really a very heterogeneous group with widely varying opinions that is inordinately influenced by special interest and activist groups. When dealing with radwaste management, it is likely that more than 99% of “the public” has little knowledge of or opinions regarding this issue.

In conclusion, a major part of the consternation over how to safely manage radioactive wastes has been created by the scientists themselves. The 1957 Board, all scientifically educated and knowledgeable, failed in that they did not perform a holistic risk evaluation of the entire radioactive waste management problem and just addressed how to protect future generations without thoughts about what additional risks that would create for the present generation. That has been continued by the propensity of scientists to provide a ‘conservative’ assessment based on everything that could go wrong but without any association to the probability of occurrence. Finally, those attitudes are compounded by scientists who know that attempting to create a numerical model to forecast the future is unrealistic but persist in pushing the idea because it is an intellectual challenge to build a model even if there is no way to know how accurate it is.

That attitude persists among the scientists even today. For example, recent discussions at the 2009 Carnegie International Nonproliferation Conference [12] on the nuclear renaissance concentrated almost totally on the front-end concerns – money, skilled workforce, etc. with little regard to the associated radioactive waste disposal. What discussion there was about radioactive waste disposal centered on the deep geological repository concept as the only acceptable disposal mechanism rather than addressing the issue from an integrated and holistic risk management perspective.

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